Basic Hearing and Echolocation Mechanisms of Marine Mammals: Measured Auditory Evoked Potential and Behavioral Experiments FY 2008

Paul E. Nachtigall
Marine Mammal Research Program
Hawaii Institute of Marine Biology
P.O. Box 1106
Kailua, Hawaii 96734
phone: (808) 247-5297 fax: (808) 247-5831 email: nachtiga@hawaii.edu

Award Number: N0001405-1-0738
http://www.hawaii.edu/HIMB/

LONG-TERM GOALS

Examine the control of hearing during echolocation.

Broaden the baseline of hearing measures of marine mammals by increasing the number of animals and species measured. The effects of sound on wild populations of animals can best be determined if baseline hearing measures are known.

Improve the measurement of marine mammal hearing by developing and refining hearing procedures particularly those that will rapidly measure the hearing of stranded and temporarily caught animals.

Comparatively examine the basic hearing mechanisms of marine mammal species.

Compare the auditory evoked potential and behavior psychophysical methods for examining hearing in odontocetes.

Examine the effects of loud sound on dolphin hearing and temporary threshold shifts – particularly those frequencies used in the midfrequency sonars like the 53 C.

Develop an understanding of the basic processes of odontocete echolocation.

Develop and refine the measurement of hearing during echolocation particularly the hearing of the outgoing signals and the echoes from nearby and distant targets.

Examine automatic gain control mechanisms in odontocete echolocation.

Develop an understanding of the basic processes used by odontocetes to actively discriminate fine differences in echolocation targets and to model those processes for use in the development of improved sonars.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Basic Hearing and Echolocation Mechanisms of Marine Mammals: Measured Auditory Evoked Potential and Behavioral Experiments FY 2008**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Hawaii Institute of Marine Biology,Marine Mammal Research Program,P.O. Box 1106,Kailua,HI,96734**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

OBJECTIVES

Marine Mammal sensory systems have evolved to effectively use acoustic energy in the oceans. My objectives are to develop a basic understanding of hearing and echolocation so that knowledge can then be applied to the solution of practical problems as they arise. The most basic hearing measurement is the audiogram which is a series of thresholds across frequencies. It basically describes the hearing of an organism. Of the 85 species of dolphins and whales we now have audiograms on 14 species. Audiograms on additional cetacean, and other marine mammal, species may be obtained from stranded animals, from animals in captive display situations, and from catch and release scenarios. We intend to obtain as many valid audiograms as possible as we seek new opportunities in new situations. Other hearing measures such as directionality of hearing, and the mechanisms underlying that directionality, are also very important and little is known on most marine mammals. These measures will also be obtained whenever possible.

Most of our initial audiometric work measured hearing using behavioral responses (Nachtigall et al, 2000). Measures of auditory evoked potentials (AEP) produce the benefit of being obtained rapidly without requiring captivity or lengthy training. Our work (Yuen et al, 2005) shows that the two procedures, while not producing exactly the same results, are certainly comparable. So, we intend to continue using AEP measures to measure the hearing of new species and to continue to measure hearing in other situations.

Our initial work on temporary threshold shifts (Nachtigall et al 2003, 2004) with exposures up to 50 minutes combined with shorter term exposures led to an equal energy hypothesis in which it was assumed that the amount of TTS was dependent on the amount of energy received relatively independent of the time of exposure. An objective of our recent work (Mooney et al, 2006) has been to examine whether the equal energy hypothesis is valid for short exposure times.

While much was known about outgoing dolphin echolocation signals, little was known about what animals heard while they echolocated (Supin et al. 2003, 2004, 2005) until we developed a procedure to measure AEPs during active echolocation experiments. Our current objective is to examine the automatic gain control of hearing during echolocation with targets present and absent.

APPROACH

The ability to obtain hearing data on new species requires opportunistic motivated action. I have a permit from the NMFS to test the hearing of stranded animals and keep in touch with the stranding networks in the US to keep opportunities for testing stranded animals available. Animals in public display facilities occasionally become available for hearing examination especially if the audiometric tests are conducted for short periods of time like those for AEP measures. The AEP measures can also be used on boats so that temporarily caught animals can be tested. All of these approaches allow us to increase the species and the number of animals tested. We work closely with Alexander Ya. Supin from the Russian Academy of Sciences to test the hearing of new species of animals, especially those that require a new technique or adaptations to new procedures.

We primarily use the envelope following response auditory evoked potential approach in which we present amplitude modulated sounds to the animals and monitor the brain wave patterns in response to the amplitude modulation rate. While that works well for cetaceans, we also use individual tone pip

AEPs for those marine mammals, like the polar bear, that are not as prone to rapidly follow amplitude modulated stimuli. Our work with the polar bear is conducted with the staff of Kolmården Djurpark in Sweden, particularly Mats Amundin.

Temporary threshold shift work is primarily accomplished by testing the hearing of the dolphin, exposing it to sound, then retesting hearing immediately using evoked potential measures. Last year we presented intermittent sounds produced by navy midfrequency sonar to see whether the sonars produce the predicted amount of TTS.

Hearing is examined during echolocation by measuring the hearing when the outgoing pulse is produced and when the echo is returned by measuring the brain response timed from the outgoing pulse. Target strength is varied by changing the distance and target strength of the targets. The animal is required to echolocate and report the presence or absence of the target and AEP recordings of its hearing while doing that are the important dependent variable.

WORK COMPLETED

Tested TTS with both long and short exposures and further tested the equal energy hypothesis.

Exposed subjects to 53C sonar pings and tested the number of pings and level required to produce TTS

Measured the hearing of the false killer whale during echolocation when targets were present and absent.

Examined whether or not there were additional automatic gain control mechanisms in the hearing of the false killer whale during echolocation.

Examined the directionality of hearing in the beluga whale.

RESULTS

TTS was found not to follow the Equal Energy Hypothesis. Short exposures took more energy to produce shift than longer exposures.

Found that the 53C sonar sound would require the animal to be approximately 40 meters from the ship for 5 minutes to produce TTS.

Found that an echolocating False Killer Whale controls its own hearing during echolocation to ‘lock on’ to the echo from the target and adjusts its hearing to maximize the hearing of that echo. The animal **adjusts its hearing** during echolocation.

Found that hearing overall changed by 20 dB. When targets were absent the animal appeared to be in a ‘search mode’ and hearing was 20 dB better than when targets were already detected. This difference in hearing occurred to both the animals own clicks and a 22.5kHz sound presented and tested during the echolocation task (see Figure 1)

Found that there is an automatic gain control in the hearing system of an echolocating false killer whale. There are at least three mechanisms of automatic gain control in odontocete echolocation – echolocation and hearing are a very dynamic process.

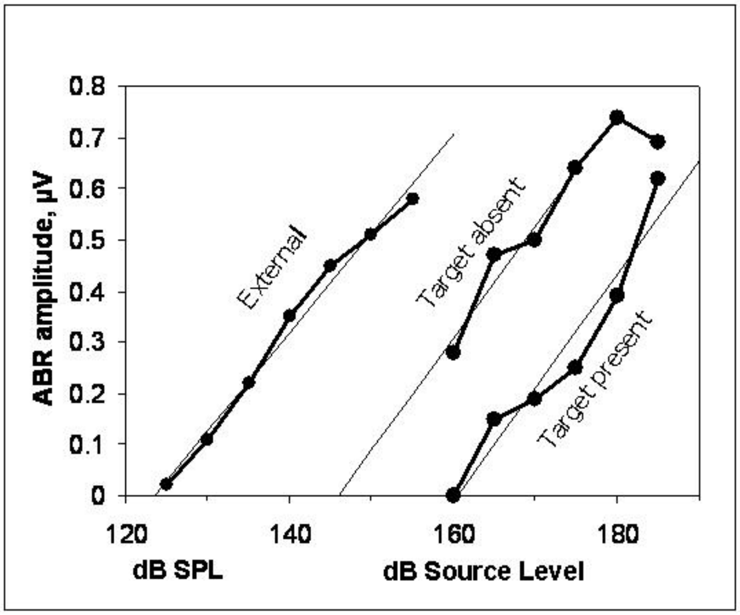

Figure 1. AEP (hearing) levels to: (a) Simulated false killer whale clicks presented in front of the animal, (2) outgoing clicks when targets were absent, (3) outgoing clicks when targets were present Note that hearing is 20 dB better when no targets are present. (Supin, A.Ya., Nachtigall, P.E. and Breese, M. (2008) Hearing sensitivity during target presence and absence while a whale echolocates. Journal of the Acoustical Society of America, 123, 534-541)

Beluga whales hear differently than bottlenosed dolphins. They hear best on the tip of the rostrum while bottlenosed dolphins do not.

IMPACT/APPLICATIONS

We now know the number and level of 53 C Sonar pings it takes to produce TTS in a bottlenosed dolphin. The data from the sonar fit our general algorithm for predicting TTS. Assuming a sonar source level of 235 dB and spherical spreading loss, the dolphin would have to spend over 5 minutes 40 meters from the source in order to produce TTS.

The total energy likely to produce TTS is greater for short sounds than it is for longer sounds. Shorter exposures of an equal amount of energy are less likely to produce temporary hearing loss in dolphins.

At least some delphinids hear very well up to 180 kHz, an area where many high frequency sonars operate.

We still do not know the hearing range and sensitivity of the mysticete whales. We presume they hear low frequencies, but perhaps like the polar bears, they hear much higher frequencies than we assume. If that is true, it is reasonable to be concerned about the effects of sound on mysticete whales. The mysticete whale hearing issue remains and important one to be resolved.

Odontocete echolocation is a very dynamic process in which the hearing of the animal is changing to meet the situation encountered in the environment and the targets. There is no other auditory system that is controlled in this manner. The animal's overall hearing changes while it echolocates.

All odontocetes are not alike. Belugas hear differently. We must be cautious when we extrapolate from species to species. More work is needed.

TRANSITIONS

The 53C Sonar data can be used to predict ranges for potential hearing damage to at least one odontocete species. The SPAWARSYSCEN in San Diego California uses the basic procedure that we developed to test dolphin hearing with auditory evoked potentials in research and also to measure the hearing of Navy systems animals.

RELATED PROJECTS

In a related project, funded via the University of Southern Denmark with permits from the Icelandic government, we examined the hearing of the white beaked dolphin. It was believed that white-beaked dolphins heard up to 250 kHz. While they did not hear that high, we found that they did hear up to 180 kHz by examining their hearing in a catch and release program off of a fishing boat in Icelandic waters. This new technique demonstrated that animals could be successfully caught, their hearing measured, and then successfully released within 90 minutes time with no harm to the animals.

In a similar related project, funded by the Joint Industry Program, we had the opportunity to attempt to catch a wild minke whale to measure its hearing. While we were not successful, this was the first attempt to capture a mysticete whale to measure its hearing. No large mysticete whale has been audiometrically examined.

REFERENCES

Mooney, T.A., Nachtigall, P.E., Au, W.W.L., Breese, M. and Vlachos, S. Temporary threshold shifts in the bottlenose dolphin (*Tursiops truncatus*) varying noise duration and intensity. Acoustical Society of America Meeting. Honolulu Hawaii, 1 December 2006

Nachtigall, P.E., Lemonds, D.W., and Roitblat, H. L. (2000) Psychoacoustic Studies of Whale and Dolphin Hearing. In: Au, W.W.L, Popper, A.N. and Fay R.J. (eds) Hearing By Whales, Springer-Verlag, New York pp. 330-364.

Nachtigall, P.E., Pawlowski, J. L., and Au W.W.L. (2003) Temporary threshold shifts and recovery following noise exposure in the Atlantic Bottlenosed dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 113(6) 3425-3429

Nachtigall, P.E., Supin, A.Ya. Pawloski, J. L and Au, W.W.L. (2004) Temporary threshold shifts after noise exposure in a bottlenosed dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. *Marine Mammal Science,* 20(4), 673-687

Supin, A.Ya., Nachtigall, P.E., Pawloski, J.L., and Au, W.W.L. (2003) Evoked potential recording during echolocation in a false killer whale (*Pseudorca crassidens*). *Journal of the Acoustical Society of America,* 113(5)**,** 2408-2411

Supin, A. Ya., **,** Au. W.W.L. and Breese, M. (2004) The interaction of outgoing echolocation pulses and echoes in the false killer whale's auditory system: evoked potential study *Journal of the Acoustical Society of America.* 115(6) 3218-3225

Supin, A. Ya., Nachtigall, P.E., Au, W.W.L, and Breese, M. (2005) Invariance of echo-responses to target strength and distance in an echolocating false killer whale: evoked potential study. *Journal of the Acoustical Society of America,*117(6), 3928-3935

Yuen, M.E., Nachtigall, P.E., and Supin, A.Ya., and Breese, M. (2005) Behavioral and auditory evoked potential audiograms of a false killer whale (*Pseudorca crassidens*). *Journal of the Acoustical Society of America*, 118 (4) 2688-2695

PUBLICATIONS

Nachtigall, P.E., Reichmuth, C. and Schusterman, R.J. (2008) Healthy stranded animals and laboratory research . *Marine Mammal Science* 24, 746.

Nachtigall, P.E. and Supin, A. Ya., (2008) A false killer whale adjusts its hearing when it echolocates. (Invited Manuscript) *Journal of Experimental Biology,* 211, 1714-1718

Nachtigall, P. E., Mooney T.A., Taylor K.A., Miller L.A., Rasmussen M. H., Akamatsu T., Teilman J., Linnenschmidt M., and Vikingsson G. A. (2008) Shipboard measurements of the hearing of the white-beaked dolphin, *Lagenorhynchus albirostris. Journal of Experimental Biology* 211, 642-647**.**

Supin, A.Ya., Nachtigall, P.E. and Breese, M. (2008) Hearing sensitivity during target presence and absence while a whale echolocates. *Journal of the Acoustical Society of America,* 123, 534-541

Southall, B.L.,Bowles,A.E.,Ellison,W.T., Finneran, J.J.,Gentry, R.L.,Greene C.R.Jr.,Kastak D.,Ketten,D.R.,Miller, J.H. ,Nachtigall , P.E.,Richardson, W.J., Thomas, J.A,.Tyack, P.L. (2007) Marine Mammal Noise Exposure: Proposed Criteria based on Current Scientific Evidence. (Aquatic Mammals – Special Tutorial Publication) *Aquatic Mammals* 411-509

Ibsen, S.D., Au, W.W.L**.** Nachtigall, P.E. (2007) Changes in signal parameters over time for an echolocating Atlantic bottlenose dolphin performing the same target discrimination task. *Journal of the Acoustical Society of America*, 122, 2446-2450

Muller, M.W., Au, W.W.L., Nachtigall, P.E., Allen, J.S. and Breese, M. (2007) Phantom echo highlight amplitude and temporal difference resolutions of an echolocating dolphin *Tursiops truncatus. Journal of the Acoustical Society of America*, 122**,** 2255-2262

Mooney, T.A., Au, W.W.L., Nachtigall, P.E. and Trippel, E.A. (2007) Acoustic and stiffness properties of gillnets as they relate to small cetacean bycatch. *ICES Journal of Marine Science,* 64, 1-9.

André, M. and Nachtigall, P.E. (2007) Electrophysiological measurements of hearing in marine mammals *Aquatic Mammal*s, 33 (1), 1-6

Nachtigall, P.E., Mooney, T.A., Taylor, K.A., and Yuen, M.L. (2007) Hearing and Auditory Evoked Potential Methods Applied to Odontocete Cetaceans. *Aquatic Mammals*, 33 (1), 6-13

Taylor, K.A., Nachtigall, P.E. Mooney, T.A., Supin, A. Ya., and Yuen, M.L. (2007) A portable system for theevaluation of the auditory capabilities of marine mammals. *Aquatic Mammals* 33.1, 93-99.

Yuen, M.L., Nachtigall, P.E.**,** Breese, M. and Vlachos, S. (2007) The perception of complex tones by a false killer whale (*Pseudorca crassidens*) *Journal of the Acoustical Society of America, 121, 1768-1774*

Nachtigall, P.E.**,** Supin A. Ya, Amundin, M., Röken, B., Møller, T., Mooney, T.A.,Taylor, K.A., & Yuen, M.E., (2007) Polar bear(*Ursus maritimus*) hearing measured with auditory evoked potentials. *Journal of Experimental Biology,* 210, 1116-1122

Supin A.Ya, Nachtigall, P.E., and Breese, M. (2007) Evoked-potential recovery during double click stimulation in a whale: A possibility of biosonar automatic gain control. *Journal of the Acoustical Society of America,* 121**,** (1) 618-625

HONORS/AWARDS/PRIZES

Invited manuscript to special Neurosensory Ecology edition of *The Journal of Experimental Biology*.. Nachtigall, P.E. and Supin, A. Ya., (2008) A false killer whale adjusts its hearing when it echolocates. (Invited Manuscript) *Journal of Experimental Biology,* 211, 1714-1718.

Invited paper to Meeting - Acoustics 08, Paris France. Nachtigall, P.E. & Supin, A. Ya. Hearing adjustment during echolocation measured with evoked potentials.